ATLAS Technical Coordination
Radiation Hardness Assurance Working Group
Coordinator: M. Dentan.

Report of the
Third meeting of the ATLAS Radiation Hardness Assurance Working Group
CERN, 304-1-001B, 10 February 2000, 9:00-16:00.

Content:

Attendees:

Igor Mandic (Ljubljana / Atlas SCT), Christophe Delataille (LAL / Atlas LARG), Marie-Laure Andrieux (Grenoble / Atlas LARG), Francois Vazeille (Clermont / Atlas Tile), Georges Blanchot (Barcellone / Atlas Tile), Osamu Sasaki (KEK / Atlas Muons TGC), Kazami Hasuko (ICEPP Tokyo / ATLAS Muon TGC), Chikara Fukunaga (KEK / Atlas Muon TGC), Riccardo Vari (INFN Roma / Atlas Muons RPC), Nachman Lupu (Technion / Atlas / Muon), Harri Tyrvainen (CERN / Atlas Magnet Control), Bjorn Hallgren (CERN / Atlas DCS), Joaquin Inigo-Golfin (CERN / Atlas Crane), Werner Kubischta (CERN / Atlas cryogenics), Philippe Farthouat (CERN / Atlas TC & TRT), Martin Dentan (CERN/ Atlas TC), Federico Faccio (CERN / COTS), Marc Tavlet (CERN / TIS).

Date and place of the next (4th) RHAWG meeting:

Monday 15 May 2000, CERN, Conference Room 40-R-A10.

I. INTRODUCTION: ATLAS POLICY ON RADIATION TOLERANT ELECTRONICS REVISION 2

Revision 2 of the ATLAS Policy on Radiation Tolerant Electronics was studied and approved at technical level by representatives of ATLAS sub-systems during the 2nd RHA-WG meeting (7/12/99). The principles of this revision were summarised in the report of that meeting and submitted on December 17 to ATLAS EB for approval. An extended written summary of this revision 2 was again studied and approved at technical level by representatives of ATLAS sub-systems during the 3 rd RHA-WG meeting (10/2/00). This extended summary was sent to ATLAS EB on February 11. Sub-systems are currently analysing this document and will give feedback before official approval by ATLAS EB.

A first feedback given by ATLAS sub-systems representatives during the 3rd RHA-WG is summarised in appendix I.

II. SEE AT SYSTEM LEVEL

II.1. Current status of SEE issues

SEE could be a serious issue for some of the electronics systems, even in the caverns. Appendix II summarises the work done by sub-systems in this field. This work (definition of the maximum SEE rates acceptable by the sub-systems, qualification of components, study of a strategy against SEE, …) is generally less advanced than the work done on cumulated radiation effects (total ionising dose, displacement damages). To accelerate their work in the SEE field, sub-systems are willing to coordinate their efforts with the help of ATLAS TC / RHAWG (see section II.3).

Reminder:

- Soft SEE: transient bit error, bit flip in a memory. The maximum soft SEE rate must be defined by each sub-system for each electronics functionality. Components and architectures must be chosen and tested in order to satisfy these maximum rates.
- Hard SEE: permanent bit error; stacked bit in a memory. The maximum hard SEE rate must be defined by each sub-system for each electronics functionality. Components and architectures must be chosen and tested in order to satisfy these maximum rates.
- Destructive SEE: latch-up, gate rupture, burnout. For safety reasons, devices sensitive to destructive SEE are forbidden in ATLAS, except when robust architectural solutions protect them fully against thermal destruction and avoid any risk of fire at system level. Components and architectures must be chosen and tested in order to satisfy these requirements.

II.2. Basic solutions to reduce SEE rates

Neutron shielding

Polyethylene is an attractive material for neutron shielding, but it induces risks of fire and of explosion (irradiations induces H_2 emission), and it is not mechanically stable in long term. Appendix III summarises the advantages and disadvantages of this material and of several other materials suitable for neutron shielding. For more information, contact Marc Tavlet (CERN-TIS; phone +41 (0)22 767 37 17, E-mail Marc.Tavlet@cern.ch).

Technological and architectural solutions against SEE

Several technological and architectural solutions against SEE are summarised in appendix IV. For more information, contact F. Faccio (CERN-EP/MIC; phone +41 (0)22 767 20 65; E-mail Federico.Faccio@cern.ch).

II.3. Coordination of SEE tests

ATLAS sub-systems are willing to share experience and results in SEE testing, and to coordinate the use of SEE test radiation facilities when it is possible. They agree on the following approach:

- Radiation test methods: Sub-systems will apply ATLAS standard SEE tests methods and will summarise SEE test results using the standard report document given in ATLAS Policy on Radiation test method revision 2. This will facilitate the interpretation of the tests and the sharing of test results between sub-systems;
- Electronics components database: ATLAS TC will add to the RHA web page a database that will contain test results obtained by sub-systems on the various ATLAS electronics components. To fill this database, sub-systems will provide the RHA-WG convenor with SEE test results written using the standard report document.
- Agenda of SEE tests: ATLAS TC will add to the ATLAS RHA web page a section that will contain the agenda of SEE tests scheduled by ATLAS sub-systems. To fill this agenda, sub-systems are invited to regularly provide the RHA-WG convenor with the dates, places and purposes of the foreseen SEE test campaigns. This agenda will enable sub-systems to coordinate the use of SEE test radiation facilities.
- ATLAS-RHA Web page can be found at:
  http://www.cern.ch/Atlas/GROUPS/FRONTEND/radhard.htm

III. RADIATION TOLERANT POWER SUPPLIES

III.1. Summary of low voltage power supplies developments

Radiation constraints:

They depend on the location chosen for the power supplies. There are three possibilities:

- In USA15 or in US15 rooms, there will be no radiation;
- In UX15 on the outer shell of the ATLAS detector, the radiation levels will be:
  - Total Ionising Dose (TID): negligible (less than 1 krad in 10 years);
  - Non Ionising Energy Loss (NIEL): about 1E11 n/cm2 (1 MeV eq.) in 10 years;
  - Single Event Effects (SEE): the level of interest to estimate soft SEU rates is the *total fluence of hadrons > 20 MeV*, currently under computation by Mike Shupe.
- Inside ATLAS detector, the radiation levels will be those given by the ATLAS Policy on radiation tolerant electronics revision 2 (currently under computation by Mike Shupe).

There are several approaches to cope with neutron issues in UX15:

- Qualification of the electronics systems by actual neutron tests;
- Identification and test of the system's components that are known to be potentially sensitive to neutrons; replacement (if necessary) by more neutron tolerant devices;
- Neutron shielding (see II.2).

Voltages:

Eighteen different voltages will be used by ATLAS sub-systems. Some of the power supplies will be exposed to radiations in UX15 or in ATLAS; other will be free of radiation in USA15. Table 1 summarises some of the location of low voltage power supplies and some of the values of the biases required by the various sub-systems.

Bias (V)	**+48.0**	**+24.0**	**+15.0**	**+10.0**	**+9.0**	**+7.0**	**+6.0**	**+5.0**	**+4.0**	**+3.5**	**+3.3**	**+2.5**	**+3.0**	**+1.0**	**-3.0**	**-5.0**	**-6.0**	**-15.0**
PIXEL																		
TRT								X								X		
SCT				X		X			X	X				X				
LARG				cracks			cracks	cracks					cracks		cracks		cracks	
TILE			gap					gap			gap					gap		gap
CSC								X			X							
MDT								X			X							
TGC								X			X		X		X			
RPC											X	X						
Magnet	USA15	USA15	USA15															USA15
DCS[1]			USA15	USA15	SA15	SA15	x	x	x	x	x							
Cryo.																		

Table 1

Power supplies under study or development:

Appendix V summarises the prototypes power supplies that are currently under study or under development by ATLAS sub-systems, and the radiation tests that are performed or planned to qualify power supplies. Several commonalities appear in these power supplies as well as in the radiation tests made on them.

III.2. Coordination of developments and tests of power supplies

Sub-systems agree to examine the possibilities of cooperation in their effort for study or development of LV power supplies, and in the radiation tests they perform on power supplies or on elementary sub-element of power supply. Cooperation may concern voltages and sub-systems summarised in table 2:

Voltage	**Sub-systems**
+48.0	MAGNET, CRANE
+15.0	MAGNET, TILE
+10.0	SCT, LARG
+5.0	TRT, LARG, TILE, CSC, MDT, TGC
+3.3	TILE, CSC, MDT, TGC, RPC, DCS
+3.0	LARG, TGC
-3.0	LARG, TGC
-5.0	TRT, TILE
-15.0	MAGNET, TILE

Table 2

Discussions between sub-systems will be pursued in this field in the frame of the Robert Richter’s group “ATLAS Radiation tolerant Electronics and Power Supplies meetings” in collaboration with the ATLAS RHA-WG.

The minutes of the ATLAS “Radiation tolerant Electronics and Power Supplies meetings” organised by R. Richter since 1997 are available on the ATLAS web site: http://www.cern.ch/Atlas/GROUPS/FRONTEND/powermeeting.htm

Information on ATLAS power supplies can be found on the ATLAS web site: http://www.cern.ch/Atlas/GROUPS/FRONTEND/Powersup.htm

---

[1] For DCS, any voltage from +15V to +7V is allowed when feeding the LMB from USA15 through cables.

IV. PRE-SELECTION, QUALIFICATION AND PROCUREMENT OF COMPONENTS

IV.1. Planning of construction of the sub-systems

Table 3 summarises the dates of prototyping, pre-production and production of radiation tolerant or radiation hard electronics foreseen for some of the ATLAS sub-systems.

	Prototyping	**Pre-production**	**production**
PIXEL	2000	2001	2001 - 2002
TRT	F.E.: 2000	F.E.: 2001	F.E.: 2002
SCT	1999	2000	2001 - 2002
LARG	FEB, CALIB: 2000	FEB, CALIB: 2001	FEB, CALIB: 2002
TILE		2000	2001 - 2002
CSC			
MDT			
TGC	ASD, Slave board: 2000		
RPC		F.E.: 1999; Trigger: 2001	F.E.: 2000; Trigger: 2002
Magnet			
DCS		LMB: 2001	LMB: 2002
Crane			
Cryo.			

Table 3

The prototyping phase necessitates to pre-select radiation tolerant components and to develop radiation hard ASICs. The pre-production and the production phases necessitate to qualify radiation tolerant components. The pre-production phase also necessitates to qualify radiation hard ASICs. A certain level of coordination between sub-systems may facilitate these pre-selection and qualification steps.

IV.2. Coordination of components preselection, lots qualification and lots procurement

The sub-systems are willing to cooperate on the following items:

- Share information on radiation hard ASICs or radiation tolerant components, using the ATLAS electronics components *database* mentioned in section II.3;
- Share the use of radiation facilities using the *agenda* mentioned in section II.3.

In addition to the ATLAS electronics components database and to the ATLAS radiation tests agenda, sub-systems requests ATLAS TC (RHAWG) to place on the ATLAS web site a list of radiation facilities suitable for pre-selection and qualification of radiation tolerant components.

V. References

[1] M. Huhtinen, F. Faccio, “Computational method to estimate Single Event Upset rates in an accelerator environment”, submitted to Elsevier Preprint. See also: http://www.cern.ch/Atlas/GROUPS/FRONTEND/WWW/seu.pdf

[2] M-L. Andrieux et al., “Single Event Upset Studies of a High Speed Digital Optical Data Link”, submitted to Elsevier Preprint.

[3] Summary of the ATLAS Policy on Radiation Tolerant Electronics revision 2, submitted to ATLAS EB for approval.

[4] Ph. Calvel et al., IEEE TNS Vol. 43, No 6 (1996) 2827.

[5] R. Richter, “Minutes of the 9th meeting on radiation tolerance of electronics components in the LHC cavern”, available on the following web site: http://www.cern.ch/Atlas/GROUPS/FRONTEND/Meetings/ps990910.htm

Appendix I

First feedback fron RHA-WG representatives on the draft summary

"ATLAS Policy on Radiation Tolerant Electronics revision 2"

- Appendix 1: it could be useful to replace RTC1, RTC2 and RTC3 respectively by RTC_{TID}, RTC_{NIEL}, RTC_{SEE};
- Appendix 1: Tables summarising SRL values computed for the various location of interest in ATLAS should be included;
- Appendix 1 section 2.2.1: It should be stated that RTC3.3 = 0 (for safety reasons, components sensitive to destructive SEE are not allowed in ATLAS sub-systems).
- Appendix 2 section 1 (neutron irradiation tests) states: "during irradiation, devices must be unbiased (except in case of on line measurements, not recommended in standard test procedure)". It would be better to authorise on line measurements and to explain the precautions that are required in this case.
- Appendix 2 section 2: It should be reminded that the reference photons source for TID tests are γ photons from ^{60}Co. X-photons source can be used only after calibration (by comparing their electrical effects on components with those produced on the same components by γ photons from ^{60}Co).
- Appendix 2 section 3 states: "Only one device must be irradiated at a time". It is true only for boards containing various types of components. In the case of boards containing only identical samples (identical components placed on a board dedicated to SEE tests), if the software makes possible an individual test of each component, all the components can be irradiated together.
- Appendix 2 section 3 states: "irradiation (…) up to 1E10 protons/cm2". This statement should be replaced by "up to a fluence large enough to show a reliable SEE statistic".
- Appendix 2 section 3 states: "DUT must be replaced during SEE test if the cumulated dose produced by the protons is beyond their radiation tolerance". This statement should be replaced by: "DUT must be replaced during SEE test *when* the cumulated dose produced by the protons *reaches* their radiation tolerance".
- Appendix 2 section 3: Is it possible to perform SEE tests using 24 GeV protons instead of 200 MeV protons?
- Appendix 2 section 3: The SEE test method based on neutron irradiation and described in the paper from M-L. Andrieux et al. entitled "Single Event Upset Studies of a High Speed Digital Optical Data Link", can also be used to estimate the rate of *soft* SEEs foreseen in ATLAS.
- Appendix 4: the following radiation facilities should be added: CERI (neutrons), Louvain (protons, ions), Rome (Instituto Superior di sanita: γ photons).

Appendix II:

Work done by sub-systems on SEE issues

Pixel:

- Not represented during this meeting.

TRT:

Maximum acceptable SEE rate:

- TRT collaboration will define the maximum soft and hard SEU rates acceptable in its sub-system.

SEE measurements:

- SEU rate will be evaluated this spring using PS proton beam.

Strategy against SEE:

- The soft SEU rate is expected to be low enough (in comparison with the data flow) to be considered as a noise.
- Flags will identify corrupted control data. Periodic resets will be made to avoid long term errors.
- TRT ASICs may use special tricks to avoid spurious resets, threshold upsets, and spurious or missing L1 trigger. Threshold will be continuously read (and written) in order to avoid long term threshold upsets.

SCT:

Maximum acceptable SEE rate:

- SCT collaboration will define the maximum soft and hard SEU rates acceptable in its sub-system.

SEE measurements:

- ABC/CAFE hybrid: SEE measurements have been performed on a single hybrid using 55 MeV protons from BNL. Neither hard SEU nor destructive SEE was observed. These measurements enable one to estimate the soft SEU rate expected in one hybrid irradiated with protons: 32 soft errors / 4.64E11 proton/cm2.
- ABCD:
  - SEE measurements will be performed on this chip in spring 2000.
- DORIC:
  - SEU measurements have been performed on this chip using electrons from a ^{90}Sr source. Remark from RHAWG participants: It is not possible to perform SEE tests using electrons from a ^{90}Sr source. Indeed, such electrons do not deposit enough energy in silicon to produce SEE.
  - Other SEU measurements have been performed using 9 MeV neutron from Birmingham cyclotron. No SEU were observed at fluxes comparable to that expected in the innermost layer of the SCT.
  - Other SEU measurements have been performed using 14 MeV neutron from NPL (London). A significant bit error rate was measured, increasing with the flux and decreasing with the optical power injected in the PIN diode. This result is attributed to the creation in the PIN diode of a signal above DORIC threshold.

Remark from RHAWG participants: The BER may also results from SEE in the DORIC chip itself.

- Further SEU tests with pion beams will be done at PSI this year.

- Remarks from the RHAWG convenor:
  1/ Several particles can produce soft SEU in silicon devices. Reference [1] shows that in HEP experiments like CMS (or ATLAS), the probability of producing soft SEUs is approximately constant for all the hadrons having an energy above 20 MeV, and the contribution of hadrons below 20 MeV to the whole soft SEU rate can be neglected. It enables one to estimate the whole soft SEU rate on the basis of SEU measurements made with > 20 MeV protons. Reference [2] demonstrates that this estimation can also be made on the basis of SEU measurements made with 2-34 MeV neutrons.
  2/ Raw SEU data like those from 9 MeV and 14 MeV neutron tests mentioned above don't allow a direct prediction of neutron induced SEU rates in ATLAS. Indeed, the evaluation of neutron induced SEU rates using neutron tests necessitates the knowledge of the ATLAS neutron spectrum and the use of a specific model taking into account the various mechanisms of interaction of neutrons with silicon (eg BGR model, see [2]).
  3/ It is recommended to follow SEE standard test methods given in reference [3]. In this document, the SEE test method based on proton states that protons must have an energy comprised between 60 MeV and 200 MeV. In this range, the higher the energy, the more accurate the result.
  4/ For inner detectors, pion fluxes will dominate other hadrons fluxes. In this case, pion SEE tests will be more accurate than proton SEE tests.

Strategy against SEE:

- To be defined.

TILE:

Maximum acceptable SEE rate:

- Assuming 2 opening + repair accesses per year, Tile collaboration has estimated the maximum destructive SEE rate acceptable in the drawer: 1 dead channel per day.
- The collaboration will estimate the maximum soft and hard SEU rate acceptable in its sub-system.

SEE measurements:

- SEE measurements using ATLAS standard test procedures have not yet been performed on the TILE electronics boards.

Strategy against SEE:

- Remark from the RHAWG convenor: If SEE tests show that some of the components are sensitive to destructive SEE, a special architecture must be developed in order to protect them against thermal destruction and to protect the system against any risk of fire (current limiters, resistors, automatic latch-up detection and cancellation, …).

LARG:

Maximum acceptable SEE rate:
LARG collaboration has estimated the maximum SEU rates acceptable in its sub-system:

- Destructive SEE are not allowed.
- For critical items (those whose failure would lead to lose a whole crate, eg. SCA controller, optical links, stored parameters, power supplies, …), soft or hard SEU rate *must be negligible*.
- For data, the maximum acceptable error rate (soft SEEs) is around a few wrong bit/s among the total flow of data (3E12 bits/s).
- The maximum acceptable hard SEE rate on non-critical devices will be defined.

SEE measurements:

- GLINKs: SEE measurements have been performed on these devices with neutrons with energy ranging from 2.5 MeV up to 34 MeV. Neither hard SEU nor destructive SEE was observed. Measured soft SEU rate has been analysed using a method described in [2]. This analysis gives a SEU rate of 0.065 ± 0.030 error / (link.hour). This SEU rate includes mainly the *upsets that corrupt the synchronisation* of the receiver with the emitter during a long period of time (these SEUs make the link down up to 1 ms). Another kind of upset will occur in GLINKs: the *upsets that corrupt data bits*. The total SEU rate induced by neutrons will be the sum of these two SEU rates. However, other particles than neutrons (charged particles, mainly protons at this location of the ATLAS LARG optical emitter) will also produce SEU. The total GLINK SEU rate foreseen in actual ATLAS conditions will be extrapolated from neutron tests described in [2] by taking into account the total flux and energy distribution of all the charged particles foreseen at the place where the ATLAS LARG optical emitter will be located. The simulation of this total flux of charged particles and its energy distribution is currently in progress (Mike Shupe).
- SCA: SEE measurements will be performed in march 2000.
- Power supplies: SEE measurements will be performed at BNL by Helio Takai, using heavy ions (especially to detect destructive SEE like burnout in power MOSFETs).

Strategy against SEE:

- GLINKs Error rate will be strongly reduced by using double GLINks terminated by a logic comparator that will detect and reject corrupted data. This logic comparator will be located on the receiver, far from radiations.
- For critical items, hard SEU rate will be made negligible by redundancy or by technics of error correction.
- Remark from RHA-WG convenor: devices sensitive to destructive SEEs must be protected against thermal destruction by special architecture.

Muon-MDT:

- Not represented during this meeting.

Muon-CSC:

- Not represented during this meeting.

Muon – TGC:

Maximum acceptable SEE rate:

- Muon-TGC collaboration will define the maximum soft SEU rate acceptable, as well as the maximum hard SEU rate acceptable. The maximum soft SEU rate acceptable depends on the frequency of reloading, which is not yet known.
- Destructive SEE are not allowed.

SEE measurements:

- Soft SEU rate has been estimated using publicly available data on 200 MeV proton SEU cross section [4] and taking into account the total number of bits in the whole system. The soft SEU rate expected in the whole system is 1 soft upset / day.
- Remark from the RHAWG convenor: Actual SEU tests must be done (using standard test procedures) in order to verify the estimated soft SEU rate.

Strategy against SEE:

Two solutions will be applied to reduce the SEU rate:

- PPs and SBs will be located as close as possible to the circumference of the detector;
- Some critical circuits (control registers, …) will include majority vote logic (2 out of 3 majority). A prototype will be submitted by the end of February.

Muon-RPC:

Maximum acceptable SEE rate:

- The maximum acceptable soft and hard SEU rate will be defined in week 7.

SEE measurements:

- SEE measurements using standard test procedures have not yet been performed on the Muon-RPC electronics boards.

Strategy against SEE:

- To be defined.

Magnet Control:

Strategy against SEE:

- Magnet Control System (MCS) will be located in USA15, except MCS sensors/actuators.
- Magnet Safety System (MSS) will be located in USA15, except MSS sensors/actuators.
- Magnet Constructors Diagnostic System (CDS) will be located in USA15, except CDS sensors/actuators, fieldbus components and conditioners. However, CDS slow controls will be operated only when the beam is OFF.

DCS:

Maximum acceptable SEE rate:

- Maximum acceptable hard SEE rate: to be determined.
- Maximum acceptable soft SEE rate: see table 4 below.
- Maximum acceptable destructive SEE rate: zero.

Function	Application	Upset / node in 10 year	Bits of SRAM	Upset rates (bit/s)	Solutions
Monitoring	Temp. & Volt.	1E5	512	4E-6	Digital filters
Control	Cooling/Crates	1	512	4E-11	Interlocks

Table 4: maximum acceptable soft SEU rate in DCS

SEE measurements:

- DCS want to participate in ATLAS wide SEU tests.

Strategy against SEE:

- Selected fieldbus: CAN.
- Selected software: CANopen with error detection and correction.
- Minimise the size of nodes especially in SRAM => use of Flash memories.
- Continuous functional checks done by a 2nd processor; automatic reload of software if necessary.
- Software with error corrections in the CAN node.
- Use of rad-hard power regulators (CERN development).

Crane:

Strategy against SEE:

The two cranes (PR778 and PR779) from UX15 will be operated only when the beam is OFF.

Cryogenics:

Maximum acceptable SEE rate:

SEE measurements:

Strategy against SEE:

Appendix III:

Neutron shielding

High Density Polyethylene (HDPE): *Not recommended by TISfor the following reasons:*

- It burns easily.
- Under irradiation, polyethylene liberate hydrogen which induces risks of fire or explosion. The use of a tight container is a worse case, because the pressure of hydrogen liberated in the container may produce its explosion.
- It creeps (not self-standing in the long term).

Water:

- It needs tight containers.

Permali:

- Type "EN" = moderator only. *Not recommended by TIS* because it burns too easily according to IS-41. It does not creep.
- Type "HB" = moderator + 2% boron (neutron absorption). It is fire resistant, it does not creep, but it produces gamma rays.

Neutraline:

- It is fire resistant. It does not creep.
- For more information, contact J.Baggio (CEA-DAM, phone +33 (0)1 69 26 48 71, Baggio@Bruyeres.cea.fr).

For all these materials, ~10 cm reduces by a factor 3 the fluence of 1 MeV neutrons, and *all the spectrums are shifted towards lower energies*.

For more information, contact Marc Tavlet (CERN-TIS; phone +41 (0)22 767 37 17, Marc.Tavlet@cern.ch).

Appendix IV:

Technological and architectural solutions against SEUs

Technological solutions against SEE:

- SOI technologies *eliminate* latch-up risks and *reduce* the SEU sensitivity.
- Epitaxial technologies *reduce* the latch-up sensitivity and the SEU sensitivity.
- Guard rings *reduce* the latch-up sensitivity.

Architectural solutions against SEE:

The first solution consists in protecting the most risky devices (memories and registers where essential configurations are stored). Registers can be protected against SEE using the following approach:

- Redundancy plus error detection and correction;
- Redundancy plus voting;
- Use of static shift registers instead of dynamic shift registers. Indeed, dynamic shift registers are much more sensitive to SEU than static shift registers;
- Study of the effect of an injected charge on sensitive nodes, using SPICE. This enables one to estimate the critical charge which may produce a SEU. Then, the SEU sensitivity can be reduced by adding capacitors on the sensitive nodes.
- Use hardened D flip-flop architectures. Such architectures have been developed by the industry. They use a significantly larger silicon surface and a significantly larger current consumption than standard D flip-flop, but their threshold LET is significantly improved (around 80 to 100 instead of 10-20).

For more information, contact Federico Faccio (CERN-EP/MIC; phone +41 (0)22 767 20 65; Federico.Faccio@cern.ch).

Appendix V:

Summary of low voltage power supplies developments

Pixels:

- Not represented during this meeting.

TRT:

Low voltages that are necessary to the detector units:

- +5V (could be reduced to +3.3V)
- +3.3V
- -3.3V

Location of the power supplies:

Two solutions are being considered:

- Power supplies located in US15 (radiation free), plus cables between power supplies (US15) and detectors (UX15), plus rad-hard voltage regulators close to the silicon detectors;
- Power supplies located in UX15 on shelves on the outer shell of the ATLAS detector (rad-hard voltage regulators may also be used).

Power supplies under study:

Commercial power supplies from ELCOTRON (CH):

- Voltage adjustable from 2V to 8.5V;
- Maximum current = 64A per power supply.
- Each power supply will feed several detector units. Rad-hard voltage regulators could be placed on patch panels to maintain a constant voltage and to limit the current.
- These power supplies contains transformers and electrical motors for cooling. Due to the electromagnetic field (200 to 800 Gauss), these devices may not work in UX15 unless special measures are applied.

Radiation tests:

- Neutron tests: ?
- SEE tests to be done if location = UX15.

SCT:

Low voltages that are necessary to the detector units:

- +1.0 V (preamplifier current control);
- +3.5 V (analog circuits);
- +4.0 V (digital circuits);
- +7.0 V (LED dc bias);
- +10.0 V (PIN voltage).

Location of the power supplies:

Two solutions are being considered:

- Power supplies located in USA15 (radiation free), plus cables between power supplies (USA15) and silicon detectors (UX15), plus perhaps rad-hard voltage regulators close to the silicon detectors;
- Power supplies located in UX15 on shelves on the outer shell of the ATLAS detector.

Prototypes under study:

- Two solutions are being considered:
  - Commercial DC/DC converters ref. BXA10-12D05-S10W (Computer Products);
  - Modified commercial DC/DC converters (transformer in the regulation loop).
- SCT Low Voltage (SCTLV) prototypes contain:
  - 2 independent digitally controlled and floating power supplies (Vout max = 6V / 1.2A; and Vout max = 6V / 0.5A);
  - 4 control voltages up to 10V / 10 mA;
  - 2 logic signals.

Radiation tests:

- Neutron tests:
  - 1.4E11 n/cm2;
  - 2.0E12 n/cm2.

  Results of neutron tests:
  - Loss of communication between micro-controllers, due to bad performance of the opto-insulator ref. PC817 (SHARP): its Current Transfer Ratio (CTR) decreases down to 50% after 1.4E11n/cm2 and down to 1% after 2E12 n/cm2.
  - DC/DC converters have been damaged and provide 20% higher output voltages than nominal.

  Corrections under study:
  - Special circuitry compensating for the decrease of the opto-insulator CTR;
  - Search for a new opto-insulator having higher radiation tolerance;
  - Replace DC/DC converters by transformers;
  - Use rad-hard voltage regulators developed by ST for CERN.

  Remark from the RHA-WG convenor: Robert Richter reports in [5] that commercial opto-insulators HP 6N138/139 (Hewlett Packard) are proven to be significantly more tolerant to neutrons than several other commercial opto-insulators tested by HEP laboratories for LHC applications.
- SEE tests: to be done if location = UX15.

LARG:

Low voltages that are necessary to the system:

- +10V / 7A;
- +6V / 114A;
- +5V / 277A;
- +3V / 21A;
- -3V / 114A;
- -6V / 5A.

Location of the power supplies:

- In cracks near the front-end crates.

Prototypes under study:

- BNL is developing DC-DC converters (20A/unit) in collaboration with VICOR.
  In these converters, opto-insulators will be replaced by transformers.
- To reduce the risks of destructive SEEs, components will be operated in derated conditions.
- LARG sub-systems will intensively use rad-hard voltage regulators developed by ST for CERN.

Radiation tests:

- Total ionising dose: no failure up to 100 krads;
- Displacement damage: no failure up to 1E13 n/cm2 (1 MeV equivalent).
- SEE: tests planned at BNL facility

TILE:

Low voltages that are necessary to each block of 64 super-drawer:

- +15.0 volts / 1 A (HV distributor, I values are given for 1 superdrawer);
- + 5.0 volts / 0,5 A (HV distributor, I values are given for 1 superdrawer);
- -15V / 2A (HV distributor, I values are given for 1 superdrawer);

- + 5.0 volts (analog part of readout electronics);
- - 5.0 volts (analog part of readout electronics);
- + 5.0 volts (analog part of readout electronics);

- + 3.3 volts (digital part of readout electronics).

Location of the power supplies:

- In the gap between the fingers.

Prototypes under study:

- DC/DC converters with modifications to improve the radiation tolerance.
- Two possible manufacturers: VICOR (LARG development), or CAEN.

Radiation tests:

- To be done.

Muon-MDT:

Low voltages that are necessary to the system:

- +3.3 V (available at the front-end using voltage regulators);
- +5.0 V (available at the power supply);
- +5.0 V (DCS).

Location of the power supplies:

- Power supplies will be located in UX15 on shelves on the outer shell of the ATLAS detector.
- Voltage regulators will be located on the MDT front-end electronics boards (1 unit for each group of 24 tubes).

Prototypes under study:

- COTS power supplies tested by the CERN Pool (Bruno Allongue et al.);
- CAEN power supplies tested by CERN Pool (B. Allongue et al.) for CMS (Georgio Stefanini).
- COTS voltage regulators. If radiation tests show that they are not radiation tolerant enough, MDT will use voltage regulators developed by ST for CERN (P. Jarron).

Radiation tests:

- Total Ionising Dose: TID tests are required only for the voltage regulators located on the front-end electronics. These tests are not required for power supplies located in UX15 (the expected total ionising dose is too small to induce significant damages).
- Neutron: Standard voltage regulators have been irradiated at Prospero and are currently under analyse.
- SEE tests: to be done both on power supplies that will be located on the shelves and on voltage regulators that will be located on the front-end electronics. SEE tests will probably be done at CERI using neutrons.

Muon-CSC:

Low voltages that are necessary to the system:

- +3.3 V (available at the front-end using voltage regulators);
- +5.0 V (available at the power supply);

Location of the power supplies:

- Power supplies will be located in UX15 on shelves on the outer shell of the ATLAS detector.
- Voltage regulators will be located on the CSC front-end electronics.

Prototypes under study:

- Power supplies and voltage regulators will probably be the same than those used by MDT.

Radiation tests:

- Those made by MDT for power supplies and voltage regulators.

Muon – TGC:

Low voltages that are necessary to the system:

- +3.0 V (ASD)
- -3.0 V (ASD)
- +3.3 V (logic)
- +5.0 V (G-Links)
- +5.0 V (Electrical/Optical converters)

Location of the power supplies:

- Power supplies will be located in UX15 on shelves on the outer shell of the ATLAS detector.
- Voltage regulators will be located on the TGC front-end electronics.

Prototypes under study:

- No human resources are available to develop power supplies within the TGC group.
- Search for a collaboration within Muon groups.

Radiation tests:

- To be done.

Muon-RPC:

Low voltages that are necessary to the system:

- 3.3 volts;
- 2.5 volts obtained with a voltage regulator.

Location of the power supplies:

- Power supplies will be located in UX15 on shelves on the outer shell of the ATLAS detector.
- Voltage regulators will be located on the TGC front-end electronics.

Prototypes under study:

- To be done.

Radiation tests:

- To be done.

Magnet Control:

Low voltages that are necessary to the system:

+24V / 5A	MCS power supply;
+48V	MSS power supply (one for all the crates);
+5V / 10A	MSS voltage regulators (one per crate);
+/-15V / 3A	MSS voltage regulators (one per crate);
+24V / 2.5A	MSS voltage regulators (one per crate);

Location of the power supplies:

- USA15.

Prototypes under study:

Radiation tests:

- Not required (no radiation in USA15).

DCS:

Low voltages that are necessary to the system:

- 3.5 or 3.3 volts for Local Monitoring Box (LMB).

Location of the power supplies:

- The power supplies will be located in USA15. For these power supplies, any voltage from +15V to +7.0V is allowed. After a voltage drop along the cables (about 4 volts), the remaining voltage available at the end of the cables will be lowered to 3.5 or 3.3 volts using rad-hard voltage regulators.

Prototypes under study:

- DCS will use rad-hard voltage regulators developed by ST for CERN, to build current limiters.

Radiation tests:

- To be done for the electronics that will be located in UX15.

Crane:

Voltages that are necessary to the system:

380V / 50 Hz	(Power circuit);
220V / 50 Hz	(lighting);
48 V / 50 Hz	(Control electronics).

Prototypes under study:

- No specific study on power supply, because they are included in the commercial electronics systems that will be used for the cranes (industrial electronics systems like frequency variator, programmable automat, …).

Location of the electronics:

- Control Electronics will be located in UX15, under the vault, on the US15 side.

Radiation tests on power supplies included in the control electronics:

- Total Ionising Dose: TID tests are not required for electronics located in UX15 (the expected dose is too small to induce significant damages).
- Neutron: The problem of neutron damages must be addressed using one of the approaches proposed in section III.1.
- SEE tests: Not required for the electronics of the cranes, because it will not be powered during the presence of the beam.

Cryogenics:

Location of the power supplies:

- Power supplies will be located in USA15 (radiation free).